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Abstract

Transportation agencies often allow metal pipes as an option for cross drains under/along roads and highways. Metal culverts can corrode over time at various rates based on their environmental conditions (e.g. corrosive nature of coastal soils, high water table and saltwater intrusion). This paper focuses on applying readily available soil data such as spatial distribution of soil types and soil characteristics (e.g. pH and conductivity) towards creating a Geospatial Information System (GIS) based approach to identifying corrosion zones in the coastal regions. A combination of data, obtained from field surveys provided by the Louisiana Transportation Research Center and Web Soil Survey Data provided by Natural Resources Conservation Service, were used to create an interpolated surface representing zones corrosive to metal culverts. The role of the soil characteristics was incorporated in to the previously established corrosion models in identifying zones that will cause corrosion causing conditions for metal pipes.

Introduction

The corrosive nature of some coastal regions has led to local governing bodies and state agencies having projects within those regions to set a policy of prohibiting the use of metal culverts. This kind of policy often spreads throughout other local governing bodies and state agencies which share a similar regional environment. The corrosive nature of environmental conditions generally tend to decrease as one moves deeper in-land and away from coasts. This leads to the handicapping of some of these agencies' purchasing power as usually the initial capital investment in concrete pipes is more than corrugated metal pipes. The combined effect of soil types and environmental conditions such as pH and conductivity needs to be analyzed for one to make a decision to use a metal pipe. However, when it comes to these in-land locations, often it is not easily known to field engineers and designers how a metal pipe will respond to specific local soil types, soil characteristics and the environmental conditions. This paper presents an approach that uses spatial distribution of soil types and soil characteristics (e.g. pH and conductivity) in identifying zones where use of metal pipes is not advised as they will be susceptible to corrosion.

GIS programs such as ArcGIS can provide understanding and prediction of the spatial distribution of corrosive environments through means of spatial and geostatistical interpolation.(Childs, 2004) ArcGIS makes use of many interpolation methods that provide means for both the categorizing and quantifying of spatial data. Many of these interpolation techniques are used for analyzing varying datasets from various fields ranging from the agriculture to meteorology. There are two types of interpolation techniques in ArcGIS – deterministic and geostatistical. They both have their own advantages. Deterministic interpolation technique create surfaces based on mathematical formulas or measured points.(Childs. 2004) This method of interpolation is slightly less accurate but the accuracy can be improved with alterations of the power. Methods such as Inverse Distance Weight (IDW) are based on the extent of similarity of cells while methods such as Trend fit a smooth surface defined by a mathematical function. Geostatistical interpolation techniques such as Kriging are based on the statistics and are used for more advanced prediction surface modeling that also includes some measure of the certainty or accuracy of predictions. Spatial interpolations are described and perform by the deterministic method. As ArcGIS software continues to advance, the two interpolation techniques develop further methods of data exploitation. With the increasing capability of ArcGIS, it is possible to accurately predict the variation soil chemical properties over large geographic areas. The only limitations would be that of the data.

The use of GIS is shaping the decision making across numerous fields at all scales. This paper is focused on providing a mechanism of creating corrosion zones by utilizing ArcGIS and soil properties as mentioned previously. The sample corrosion zones presented at the end of this paper are results of some criterion set by the authors and they are not validated by any government agencies that have provided the basic data used in this study. However, depending on the criterion used in generating these corrosion zones, the results and interpolation of soil data to develop a descriptive surface of corrosion values can assist planners in making a decision on allowing/disallowing the use of metal culverts in a geographical region.

Materials and Methods

The study area of this project covers Louisiana Department of Transportation and Development (LADOTD) districts 02, 03, 07, 61 and 62. A visual reference of the districts is listed below. The approximate total area of coverage was 21,877 square miles.

Figure 1. Louisiana Coastal Regions and DOTD Districts

The data used in this project was derived from Web Soil Survey data provided by the Natural Resources Conservation Service (NRCS), United States Department of Agriculture (USDA) and field surveys provided by Louisiana Transportation Research Center (LTRC). NRCS data consisted of multiple soil and environmental datasets which are presented in polygon format covering the area of individual parishes and countries. The specific NRCS datasets that were used in this project are soil pH and resistivity. The standard map unit for this data set is 24,000 scale. The pH and conductivity data both had to be modified for the research. The units of measurement for the NRCS conductivity dataset had originally been in decisiemens per meter which is a standard among soil scientists. The conductivity units of measurements had to be converted to resistivity to match Louisiana's DOTD units of measurements which are ohm per centimeter. The conversion of units was done so that LTRC field datasets once created could be merged with NRCS datasets. The creation of a resistivity dataset was achieved in a two-step method. First, values of 0 decisiemens per meter or Null values were eliminated from the datasets which voided correlating spatial data. Then attribute table of the data set was modified. A column was added into the original dataset attribute table and field, calculating the conversion between decisiemen per meter and ohm per centimeter, this resulted the dataset having both resistivity and conductivity readings. The NRCS pH dataset was not edited. The resistivity and pH datasets were converted to point data to merge with the NRCS field surveys. The conversion of a data from polygon format to a point format does not suit the purpose of the project as it alters the data so that one single point centered within the polygon represents the value of such a large area. Therefore, multiple methods were used to accurately depict polygon data and point data format, the method displaying the greatest spatial relationship between the two was adopted for the project. The polygon datasets were first converted to raster to control the spatial variance of the data. The polygon to raster tool in ArcGIS allows the user to control the pixel or cell value of a raster regarding size, which represents the squared meter area of the surface if the data is presented in a projected coordinate system. The cell size was set to 25 meters. This value was chosen so that the spacing in the LTRC field surveys would be considered during the interpolation of the merged datasets. The raster datasets were then converted to points using the raster to point tool. This tool assigns a point value of each raster cell that is spatial center within the perimeters of that cell. The converted datasets consisted of points and their correlating values spaced 25 meter apart for areas with raster coverage.

The next step was to create spatially correlated GIS data for field surveys provided by the LTRC which covered LADOTD districts 03, 07, 61, and 62. District 02 had no field surveys and due to the extremely corrosive nature of soil it disallowed the use of metal culverts and therefore required no field surveys. The LTRC field surveys that were used to get soil data were in pdf format and their numbers are as follows 713-32-0108, 713-32-0109, 713-46-0112,713-59-0221, 713-59-0222, 276-03-0016, 276-03-0016,013-11-0026, 848-12-0016, 261-06-0030, 013-11-0026, 713-17-0041, 267-02-0022, 713-19-0109, 713-04-0001,713-59-0053, 713-63-0103, 713-63-0104, 019-30-0016, 019-30-0017, 019-30-0016, 450-91-0171, 713-27-0110, 713-27-0111, 201-01-0013, 849-02-0014, and 213-06-0008. Resistivity and pH feature classes were created by deriving a spatial location from these field surveys. To identify spatial locations from these field surveys the different ways were used, some of them are control segments, log miles, intersections, bridge numbers, google earth attachments, and field drawings included in the field surveys. While there were many more field surveys available, only the ones noted earlier had recordings which could be used to derive spatial locations. The remaining field surveys were not used in this study. The units of measurements were not altered from the PDF copies since the LTRC units of measurement were the standard for the project.

Once the four separate points feature classes e.g. LTRC pH, LTRC resistivity, NRCS pH, NRCS resistivity created, the datasets were merged per their chemical properties. The merging of the data was performed using ArcGIS' geoprocessing merge tool. The resulting point feature classes were one pH and one resistivity datasets covering the study area and consisting of a combined 60,540,719 individual points.

The same interpolation techniques was run on the both merged datasets parameters. The first interpolation technique was the IDW which is a deterministic method. The IDW assumes that value of the point decreases in weight or influence as it increases in distance from that point.(Omran 2012) The default value of the power remained the same as this method was used only as a comparison tool with the Kriging Method. The power parameter within the IDW tool controls the weight of individual points, which can be used to increase the accuracy of the interpolation method. The chemical nature of soil is heavily dependent on its immediate area and it is variable depending up on the local environmental conditions, meaning that the soil environment of an area can be vastly different then the soil environment 50 meters away specially in terms of pH. To account for this, the weight of the power was decreased. This means that the weight of individual soil point data only impacted its immediate spatial environment and had a far less greater impact as the distance increased away from the point. The Z valued field was set to pH and resistivity values of the dataset. Within the environments under the raster analysis tab a mask was set with a shapefile of the study area. The mask limits the extent of the interpolation within the study area. The processing of both the pH and resistivity dataset total an approximate time of six and a half hours with a 64-bit geoprocessing ArcGIS service. That does not mean that all IDW processes will run in this time window, just these datasets with their parameters. The mean error for this dataset was about 0.6 as shown in Figure 2 and was checked through cross-validation of the datasets. The IDW provides a quick reference to the nature of the chemical properties of soil but should not be used for accurate predictions for soil chemical properties. The IDW relies heavily on the assumptions of a predicted area by the measured

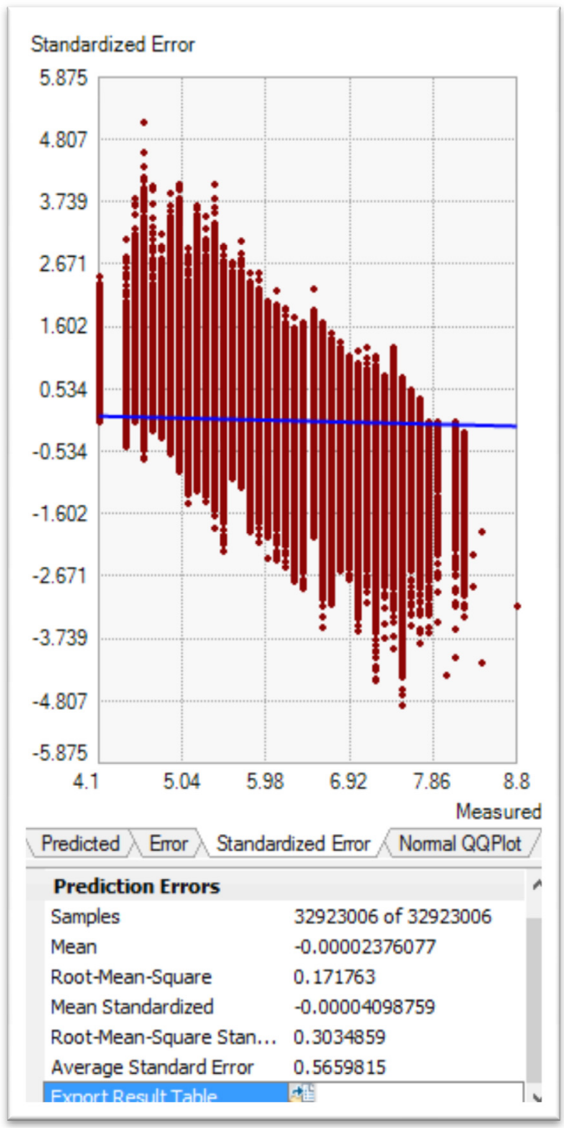

Figure 2. Cross-validation of IDW pH results

values of the surroundings and is confined by those values.(Omran. 2012) The chemical nature of soil proves that this is not always the case.

The second interpolation technique used was Empirical Bayesian Kriging (EBK). EBK is another several interpolation methods offered in ArcGIS. Kriging techniques are commonly used in agriculture, soil science and predicting pollution concertation.(Childs, 2004) EBK accounts for error that may be introduced during statistical prediction of data. The interpolation values of predicted areas are allowed to exceed the parameters of the neighboring measured values. The parameters of the EBK tool were set with some similarities to the IDW tool. The Z value field was set to the pH and resistivity readings of the datasets. The data transformation type was left at none due to possible outliners within the data. The semivariogarm model type was set to power. The data transformation type should remain at none since there should be no negative values with the data. The mask in raster analysis under the environments was also set to the same shapefile as the IDW. The mean error for the dataset was less than 0.2. During cross-validation the individual points and their errors are displayed and points with higher errors were removed. The process took 24 -36 hours to interpolate for both datasets.

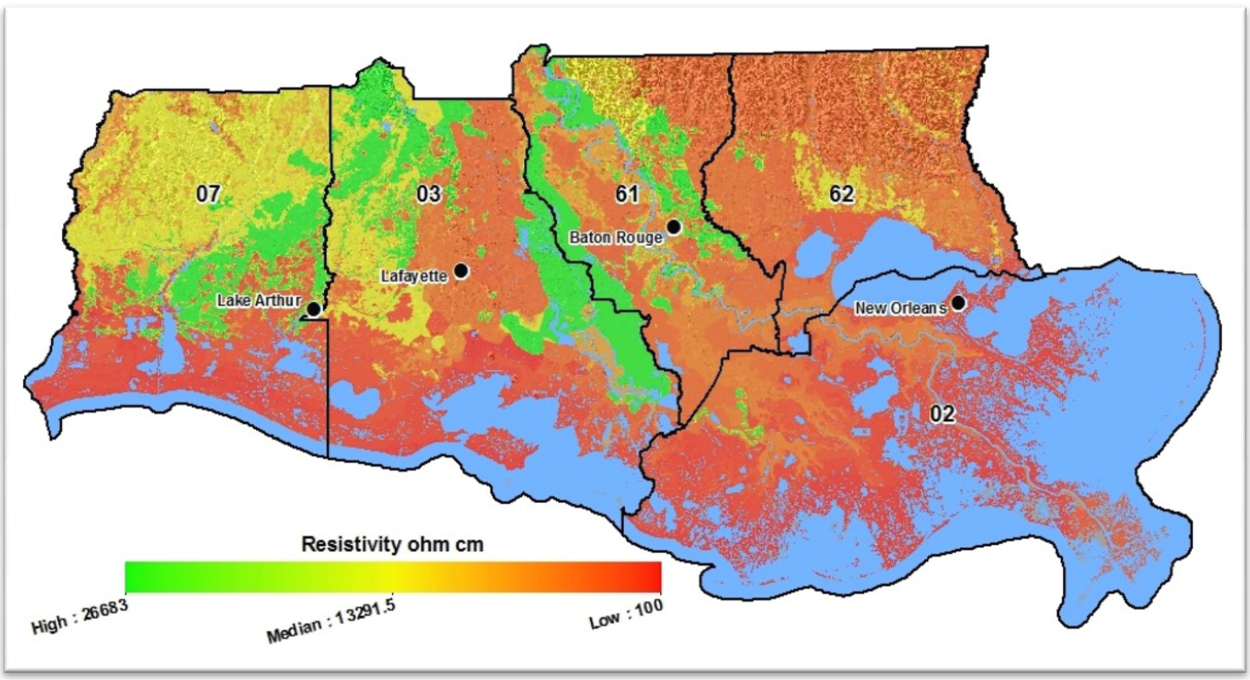

Figure 3. EBK resistivity raster format dataset

The resulting four raster datasets (e.g. pH IDW, Resistivity IDW, pH EBK, Resistivity EBK) still required some refining. The interpolations that were ran also accounted for numerous areas that consisted of water bodies. These water bodies had to be erased from the datasets. The shapefile that provided the mask for the interpolation had an erase ran on it using a Louisiana Tiger water body dataset. That shapefile was then used to run an extract by mask on all four datasets. This extracts the areas of the raster outside the waterbodies present in coastal region of Louisiana omitting the results that fell within waterbodies.

At this stage of the project, the pH and resistivity values were in a raster format and needed to be converted to polygon format so both datasets could be combined displaying intersecting spatial values. There are multiple ways to achieve this in ArcGIS depending on data format. The data needed again to be formatted again, due to the difference in the data type between the datasets. The raster datasets that resulted from the IDW techniques were in integer types which can be easily converted from raster to polygon. This was done using the Raster to Polygon tool in the Conversion toolset. The pH and resistivity raster datasets, outcomes of the EBK technique, were in float types and had to be converted into the integer type. The resistivity raster which had no decimal values outside of zero was converted using the Int tool within the Math toolset. This tool converts values that are not integers into integers. The dataset was then be converted to polygon using the Raster to Polygon tool. The pH raster which have decimal values needed to be converted in a different manner. The values of the raster had to be calculated using raster calculator to zero out the decimal places. The dataset was multiplied by 10000 to eliminate the values that were within the decimal places. The Int tool was then used to convert the values for float type to integer type. The dataset was converted to polygon using the raster to polygon tool. The polygon values for pH then had to be converted back which was done by using the field calculator made available in the attribute table menu. The pH values which were multiplied by 10000 had to be divided by 10000. The Figure 4 presents EBK pH polygon formatted dataset that was created in this project.

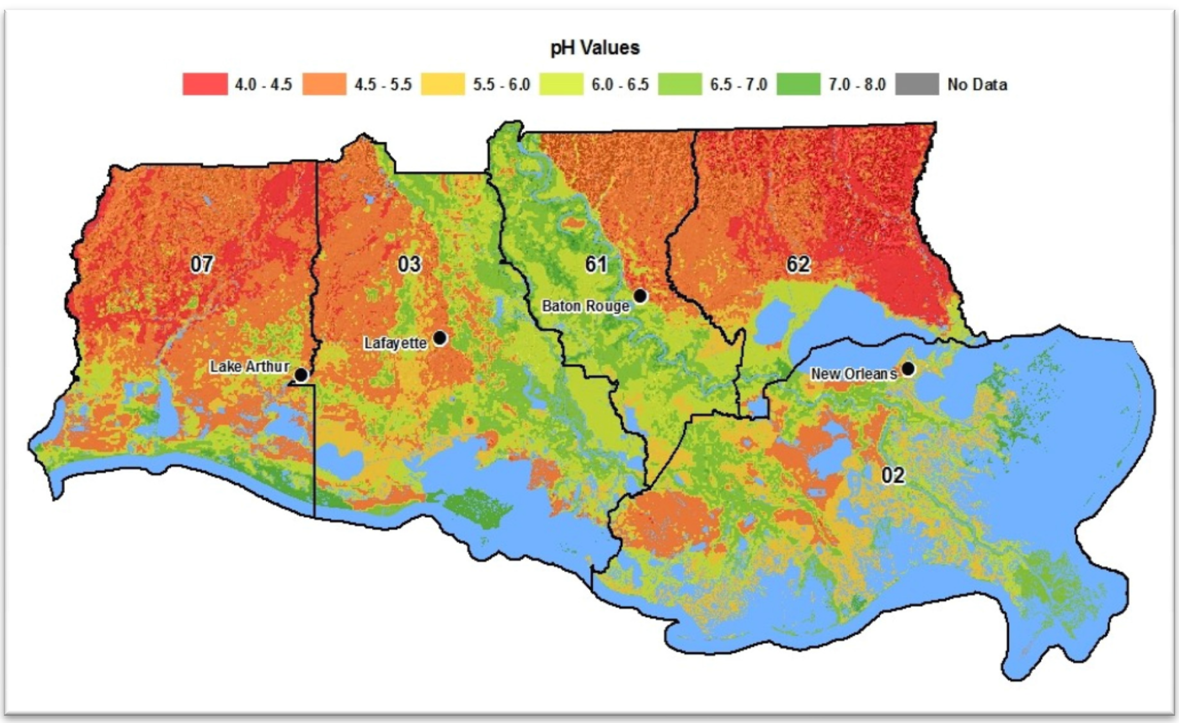

Figure 4. EBK pH polygon formatted dataset

The two separate interpolation datasets needed to be unionized so that pH and resistivity values could be combined spatially representing combined effect which is a measure of a likelihood of metal corrosion. It has been calculated based on many published models that combine soil pH and conductivity/resistivity to occurrence of corrosion. This was done by running dissolves on the four datasets based of the pH and resistivity values. The EBK and IDW datasets were then unionized so that the new polygon data represented boundary areas of shared values between pH and resistivity. The refinement of the attribute tables was the most time-consuming part of the research. The attribute values had to be categorized in a manner of life span of metal culvert and corrosive nature of the soil. The Colorado Department of Transportation (CDOT) study on determining the lifespan of metal pipes and Louisiana DOTD study on drainage pipes were referenced for determining the values of the final symbolization of the data. The Figure 5 presents this model as shown below. The attribute tables of the EBK and IDW union datasets were modified by adding two columns, one for determining average pipe life span and the other for determining the corrosive value of the soil. The resulting example corrosion map is shown in Figure 6.

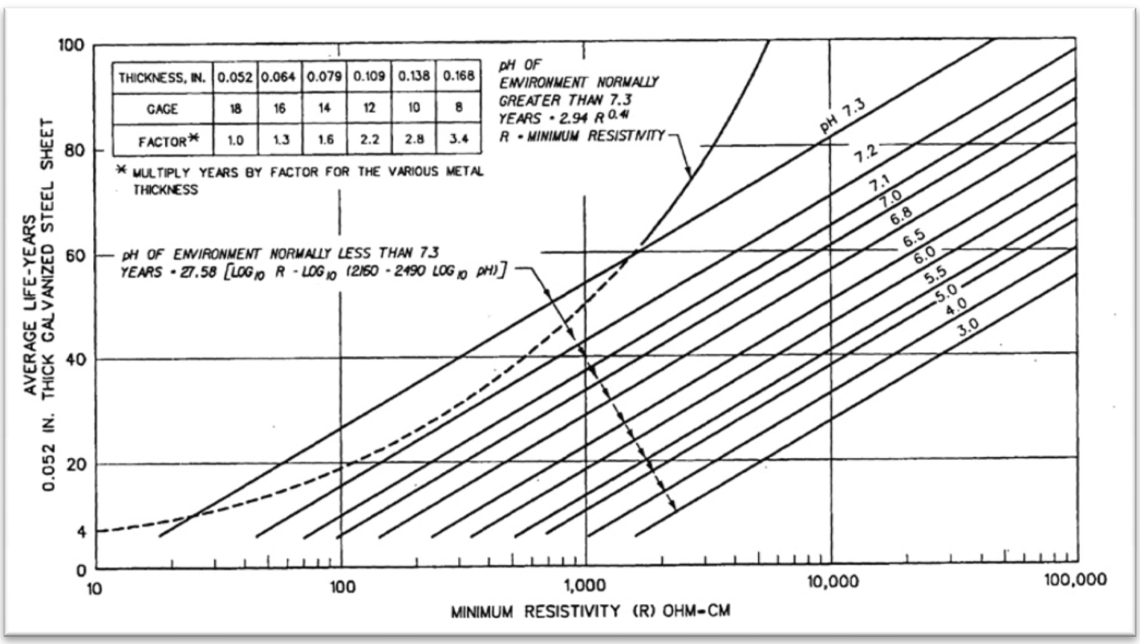

Figure 5. Corrosion model used in this work. Molinas and Mommandi (2009)

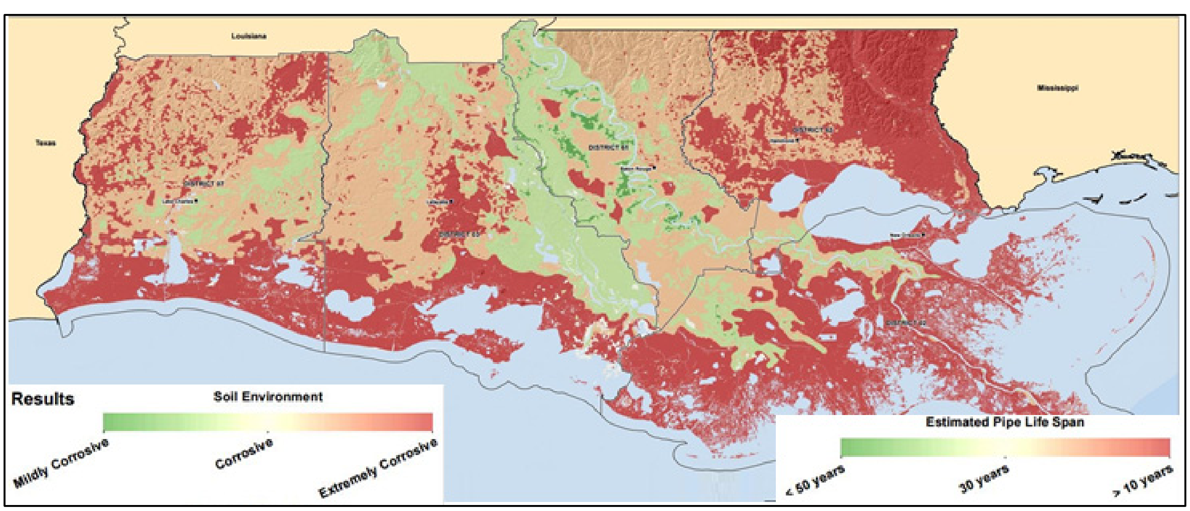

Figure 6. Example corrosion zones

Conclusions

The resulting example product, based on the criterion adopted by the authors, is a map depicting the corrosive zones of coastal Louisiana. This map is not an official map as the purpose of the exercise was to demonstrate a methodology of creating such maps. The project is still ongoing and for that reason validation and approval by the various government agencies e.g. LTRC is yet to be done. In the presented example map, the corrosive zones are divided into four categories that are mildly corrosive, corrosive, highly corrosive, and extremely corrosive. Once the project is complete, authors plan to make the datasets available for a Web based GIS platform. The map presents that most of the soil environment is corrosive in nature to metal culverts in coastal Louisiana. However, there are exceptions to this, the greater Baton Rouge area and the Atchafalaya River Basin. The data shows based on the adopted criterion that more than 70% area of the coastal region is either corrosive or displayed an area of corrosive or greater zones covering less than 30 percent of the coastal region of Louisiana is mildly corrosive. Alternatively, this means that about 70% of the area is either corrosive or highly corrosive in nature for metal pipes. This means that the average life span of metal pipes in more than 70 percent of the region is far less then forty years.

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